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Autor: Starossek, Uwe

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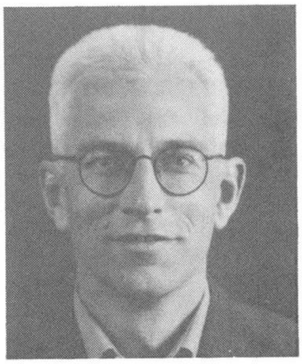
Progressive Collapse of Multi-Span Bridges – A Case Study

Uwe STAROSSEK
Dr.-Ing., P.E.
VSL Korea Co., Ltd
Seoul, Korea



Uwe Starossek, born 1956, received his civil engineering degree from RWTH Aachen, Germany in 1982 and his doctoral degree from the University of Stuttgart, Germany in 1991. He is a director of VSL Korea being responsible for the design of prestressed concrete and composite bridges. He is also a lecturer at Korea University, Seoul.

Summary

The significance of overall structural response to accidental local failure and the possibility of a failure progression throughout the structure are discussed. A progressive collapse study of a multi-span prestressed concrete bridge is presented. An analysis strategy is developed. Analytical results and the ensuing impact on the design of this bridge are discussed.

Keywords: Accidental load; local failure; progressive collapse; robustness; risk theory; response spectrum; dynamic amplification; plastic hinge; conceptual design; detailed design; design code

1. Introduction

Local failure of a structural element may cause failure of another neighboring element. In such a way, failure may progress further throughout the structure. Present design codes give little guidance on how to prevent such a progressive collapse, and designers have to address the problem on a case-by-case basis. The Northumberland Strait Crossing Project, a recently completed multi-span prestressed concrete bridge, is considered as a practical example. A progressive collapse study, performed by the designers of this bridge, is presented.

2. Northumberland Strait Crossing Project

The Northumberland Strait Crossing Project or, as now called, the Confederation Bridge is a prestressed concrete bridge between Prince Edward Island and the mainland of New Brunswick, Canada. The bridge is 12.9 km long. It consists of the main bridge of 43 continuous 250-m spans and approach viaducts on both sides of the main bridge. Possible mechanisms of, and means of design against, progressive collapse of this bridge have been studied.

The conceivable triggers of collapse are manifold. A ship could go astray or an airplane might crash into the bridge; unexpectedly strong ice formations might collide with a pier; etc. In view of the accidental nature of imaginable and unimaginable circumstances, and of the large dimensions of this structure, it would be unrealistic to design against progressive collapse just by preventing local failure at any expense. Instead, the possibility of a local failure must be accepted to the extent that it becomes the starting-point of further investigation.

A collapse triggered by the failure of pier B or pier C should come to a halt, at the latest, at hinge H1 and at pier D (see *Fig. 1*). It is assumed that the bridge girder slides off its bearings at hinges H1 and H2 so that the vertical supports, at these locations, are lost.

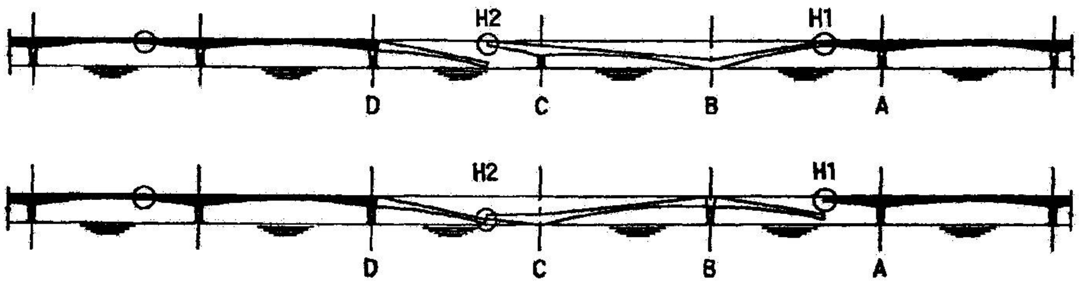


Fig. 1 Working hypothesis on progressive collapse onset

First, the response of the remaining structure to the left of H2, after a sudden loss of this hinge, has been investigated. Analysis indicated that failure of the adjacent span (to the left of D) and, thus, progressive collapse is possible. The structural system has therefore been changed. An additional hinge was inserted into each hinged span (thus having simply supported drop-in girders in every other span). Next, the response of the remaining structure to the right of H1 after a loss of this hinge has been studied. Because of the modification of the structural system, this loss does no longer need to be a sudden event. Instead, sudden loss of the opposite hinge might occur leaving the drop-in girder connected, for some time during its fall, to hinge H1. The vertical hinge force at H1, during this more gradual event, has been analyzed by establishing and solving nonlinear equations of motion (*Fig. 2*). The response of the remaining structure to this force was investigated in a linear time-history analysis and in a quasi-static plastic analysis. The latter method required determination of a dynamic amplification factor. In view of the accidental nature of the considered loading, the formation of plastic hinges was deemed allowable, and the plastic reserves of the structural system were utilized in the detailed design.

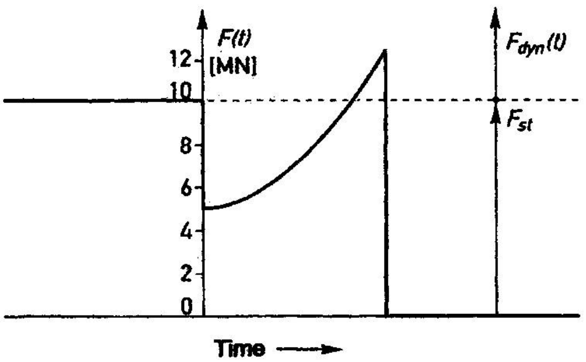


Fig. 2 Vertical force at H1

Further design modifications, due to progressive collapse, range from changes of the post-tensioned and mild steel reinforcement layout, including additional transverse reinforcement at expected plastic hinges, to a change of the superstructure's soffit line.

3. Conclusions

The requirement to avoid progressive collapse in case of local failure is an important design criterion for multi-span bridges. It can have strong impact on both conceptual design, including choice of structural system, and detailed design. Current design codes do not strictly require the prevention of progressive collapse. Recent disasters and theoretical considerations on the basis of risk theory indicate that codes should be improved to more clearly address this problem. In the meantime, owners and engineers should be encouraged to use judgement and discretion to implement the necessary measures even if not yet specifically required by codes.